Specification for the MINOS Front End Power Supplies

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Contents

1. Introduction

MINOS (Main Injector Neutrino Oscillation Search) is a High Energy Physics experiment that will be operated at Fermi National Accelerator Laboratory in Batavia, Illinois. The experiment is designed to study the properties of neutrinos, and is scheduled to run in early 2005. The electronics for the experiment is being designed and built by collaboration between Argonne National Laboratory and Fermilab. This specification describes the low-voltage power supplies needed for the front end electronics of the experiment.

The front end electronics shall be housed in semi-custom 6U crates that reside in relay racks on the detector. Each rack contains two crates and the two power supply sets, one set for each crate. Each power supply set shall supply several voltages with different current requirements. These are described in Section 2 and Section 3. Each crate consumes approximately 900 watts of power. There are approximately 45 crates in this system for the detector. We will need 55 power supplies total, including spares.

The power supplies for this application will be used to power low noise electronics. In the past, noise performance for this type of application could only be achieved by using low-noise linear supplies. New advances in switching power supply design, coupled with special abatement techniques to filter radiated and conducted output noise, have resulted in a new class of switching supplies that can meet the requirements needed for a low-noise application. The supplies for this application are required to be comparable in EMI and RFI noise performance to low-noise linear types having series pass regulators. Certain switching type supplies have been demonstrated to meet these requirements.

The input power is distributed as 208V, 60 Hz, three-phase. The supplies may use either a single phase, or two of the three-phase power supplied to the racks.

The racks are equipped with water-cooling. The heat from the power supplies will be removed using one or more heat exchangers, dedicated to cooling the two power supply sets for the rack.

A challenging aspect of the design is the packaging. The available space for each power supply set is 3U high by 19" wide by 30" deep. The space must accommodate connections to the wire harness. Good packaging design is required to fit the supplies into this space, and to provide proper ventilation and air circulation to keep the supplies from being damaged by internal heat.

We seek to have a reliable, robust design that will not create noise in the sensitive front end analog electronics. Because the front-end system uses custom integrated circuits, attention must be given to addressing failure modes so as not to damage the devices when a power supply fails.

The experimental hall is not a radiation environment. In general, the electronics will be accessible at all times. However, the experimental hall is underground, making access somewhat more difficult than a typical fixed-target experiment.

In this document, not all of the design details have been specified. Issues that remain open include the packaging details, details for cooling the supplies, the selection of power connections, and the specification of the wiring harness. For these issues, certain implementation preferences are indicated. It is expected that specific choices will be arrived at in consultation with the Project Engineer. Also, it may not be feasible to meet all of the specifications in this document. Variances may be allowed with permission from the Project Engineer

At this time, we request proposals from vendors to realize the power supplies as specified in this document. We are requesting conceptual designs that are based on individual vendor's product line, capabilities, and experiences. While new, full-custom designs are not excluded, we seek to minimize R&D costs and development time as much as possible. Proposals will be evaluated based primarily on performance, but also on cost, schedule, and risk. The successful vendor or vendors will receive an initial order for a prototype power supply set. After evaluation and design iteration, if any, we would initiate a purchase order for the production quantity of supplies. The specifications and requirements are described herein.

Nomenclature used in this document:

Power Supply Set: The collection of individual power supplies that provide the required voltages to one front end crate.

Power Supply Unit: An individual power supply that provides one or more voltages. A number of power supply units make up a set.

2. General Specifications

Each power supply set shall supply 6 voltages. A set consists of individual power supply units, each of which may provide one or more voltages. The general specifications cover the performance and operation that are common to all units in the set. The specifications for each voltage are described in Section 3.

2.1 Primary Side Configuration

2.1.1 Primary Input Power and Distribution

Line power shall be distributed to the front end racks as 208V, three-phase, 60 Hz, 5-wire WYE output configuration. Each power supply set shall use two of the three phases for primary source power. See Figure 1. All of the power supply units within a given set shall use the same two phases. The supplies shall be arranged in the experimental hall to balance the load on all phases equally.

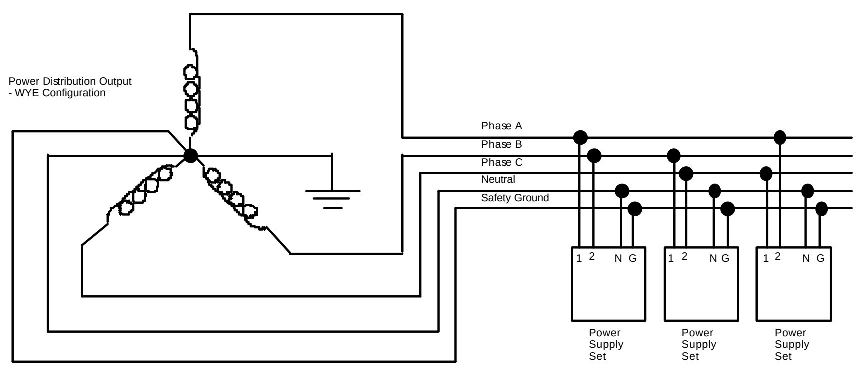

Figure 1. Primary Power Connections - Two-Phase

2.1.2 Return of Neutral Currents

The return of line currents on the primary input shall be done using a separate neutral conductor, which will be part of the power distribution system. Neutral currents are not allowed to be returned using the safety ground. ***There shall be no connection of neutral and safety ground inside the power supply set. There shall be no current to or from the power supply in the safety ground in the normal operation of the power supply, except in a fault condition.***

2.1 Primary Side Configuration (Cont.)

2.1.3 Primary Regulation

The expected variations in primary power are:

Line Voltage:	nominal +/- 10%
Line Frequency:	nominal +/- 10%
Phase Variation	nominal +/- 10%

The power supplies must be capable of operation within these ranges.

2.1.4 Transformer Shielding

It is ***desirable*** for the power supply units to have an electrostatic shield between the primary and secondary. If implemented, the shield is to be connected to the chassis near the power cord entrance. The safety ground for the power connection shall be connected to this same point. The package design should minimize conducted and radiated power line noise coupling to secondary circuits.

2.2 Secondary Side Regulation

2.2.1 Secondary Regulation Type

Linear or switching power supplies can be used in this application. In either case, the noise level emitted by the power supply must meet or be lower than the levels specified in Sections 2.3.1-2.3.3.

2.2.2 Secondary Regulation Specifications

The supplies shall maintain their nominal output voltage +/- 0.5% under any combination of the following:

Line Voltage:	nominal +/- 10%
Line Frequency:	nominal +/- 10%
Phase Variation:	nominal +/- 10%
Load:	no load to full load
Ambient Temperature:	+10 degrees C to +50 degrees C
Time:	8 hours after 10 minute warm up

This specification applies to any output voltage measured at the remote sensing point.

2.2.3 Out-of-Regulation Performance

2.2.3.1 The supplies must operate to specification for primary power variations within the ranges indicated in Section 2.2.2.

2.2.3.2 The units should drop out of regulation gracefully when outside of regulation specifications.

2.2.3.3 The units should not oscillate or switch in and out of regulation when outside of regulation specifications.

2.2.3.4 The units should not generate more noise than that due simply to passing unregulated rectified power through the secondary for low line voltage.

2.2.3.5 The units must withstand a primary voltage of nominal + 20% while operating at full load, and should shut down gracefully through thermal protection circuits if necessary. The supplies should be capable of restarting under full load when an over-voltage condition on the primary circuit has been removed.

2.3 General Performance Specifications

2.3.1 Input Noise

The conducted noise current emission reflected from the supply onto the input lines of the power supply set must comply with *FCC Class B Standard*, or the *European Standard EN55022*. The measurement method shall use a Line Input Stabilization Network (LISN), as described in *IEEE Standard 1515-2000, Section 3.22, Figures 1-2, p. 5.*

2.3.2 Radiated Noise

The noise level radiated by the power supply set must comply with *FCC Class B Standard*, or the *European Standard EN55022*.

2.3.3 Output Noise and Ripple

The output noise and ripple are critical aspects of the performance of this power supply. Each voltage in the power supply set must meet all of the following requirements. ***Any variance must be approved by the Project Engineer.***

2.3.3.1 The ripple on the DC output voltages shall be less than 2 millivolts Peak-to-Peak, as measured differentially between each power supply output and the corresponding power supply return. The definition of the output waveform is given in *IEEE Standard 1515-2000, Section 4.5.1.1, Figure 22, p. 24.* The measurement shall be performed as recommended in *IEEE Standard 1515-2000, Section 4.5.1, p. 24.* The measurement must be made using a resistive load that represents the nominal operating load of each power supply unit, as specified in Section 3.2. The bandwidth of the measurement shall be 0-50 MHz.

2.3.3.2 The DC outputs may have voltage spikes that exceed the ripple specification of 2.3.3.1, but may not be greater than 4 millivolts Peak-to-Peak, as measured differentially between each power supply output and the corresponding power supply return. The definition of the output waveform is given in *IEEE Standard 1515-2000, Section 4.5.1.1, Figure 22, p. 24.* The measurement shall be performed as recommended in *IEEE Standard 1515-2000, Section 4.5.3, pp. 25-27.* The measurement must be made using a resistive load that represents the nominal operating load of each power supply unit, as specified in Section 3.2. The bandwidth of the measurement shall be 0-50 MHz.

2.3 General Performance Specifications (Cont.)

2.3.3 Output Noise and Ripple (Cont.)

2.3.3.3 Differential conducted current noise on the DC outputs must have a spectral content less than or equal to the curve shown in Figure 2A. The measurement shall be performed as recommended in *IEEE Standard 1515-2000, Section 4.11.2, pp. 40-43*. The measurement must be made using a resistive load that represents the nominal operating load of each power supply unit, as specified in Section 3.2. The bandwidth of the measurement shall be 0-50 MHz. The spectrum analyzer measurement shall be performed in Quasi-peak Mode or Peak Mode. Currents are referred to dBμV using a normalized impedance of 50 ohms.

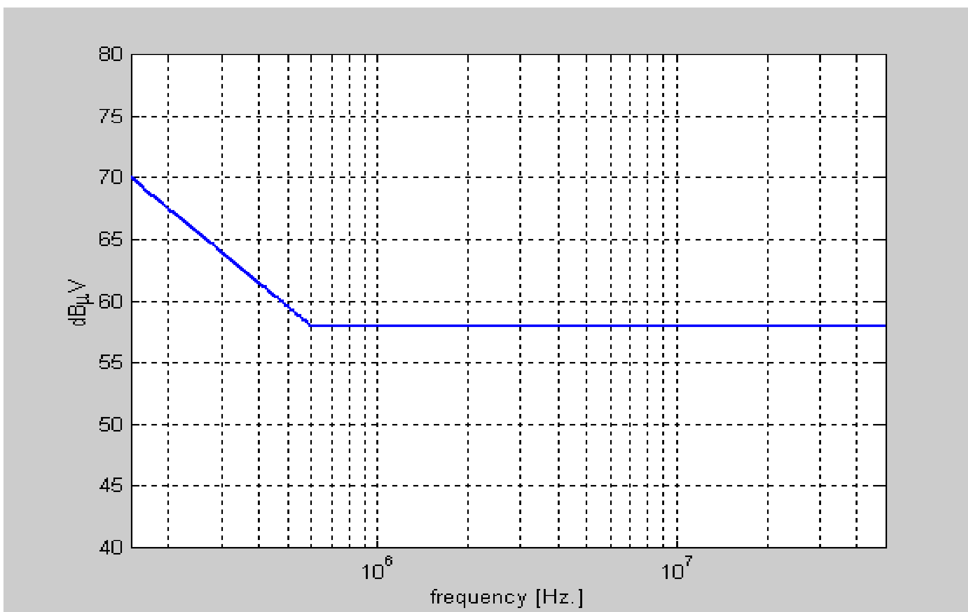

Figure 2A. Conducted Current Noise Specification

2.3 General Performance Specifications (Cont.)

2.3.3 Output Noise and Ripple (Cont.)

2.3.3.4 Common mode conducted noise current on the DC outputs must have a spectral content less than or equal to the curve shown in Figure 2B. The measurement shall be performed as recommended in *IEEE Standard 1515-2000, pp. 26-27*. The measurement must be made using a resistive load that represents the nominal operating load of each power supply unit, as specified in Section 3.2. The bandwidth of the measurement shall be 0-50 MHz. The spectrum analyzer measurement shall be performed in Quasi-peak Mode or Peak Mode. Currents are referred to dBμV using a normalized impedance of 50 ohms.

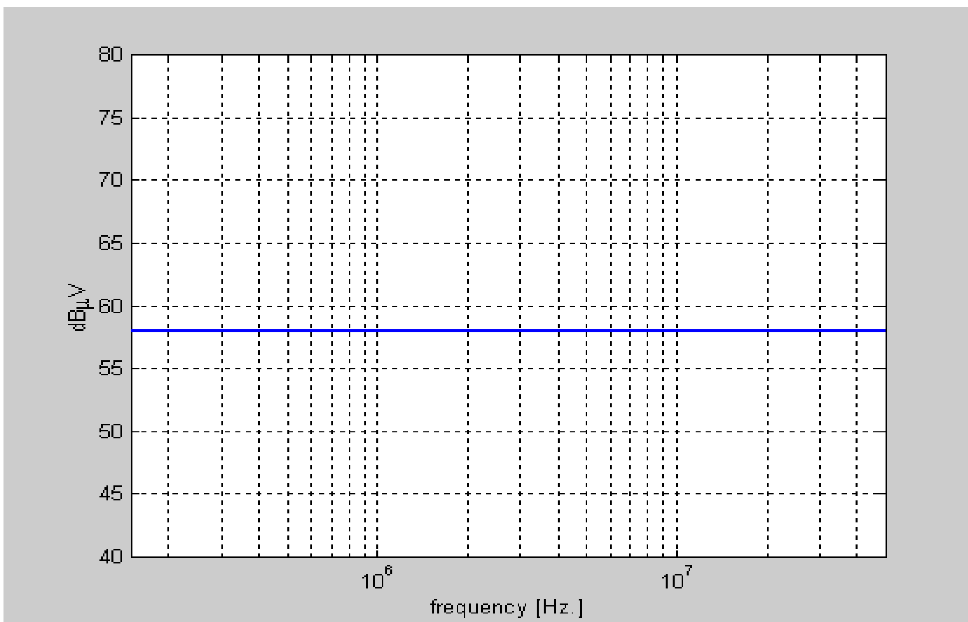

Figure 2B. Common Mode Voltage Noise Specification

2.3 General Performance Specifications (Cont.)

2.3.4 Temperature Stability

The stability over temperature shall be less than 0.1% per degree C over the range 10 degrees C to 50 degrees C. Long-term stability shall be less than 1% per year.

2.3.5 Efficiency

The power supply units shall be designed for a minimum overall efficiency of 70% at nominal output power, although higher efficiency is desirable. ***Any variance must be approved by the Project Engineer.***

2.3.6 Transient Response

Transient response is not critical.

2.4 Sensing & Control

2.4.1 Voltage Sensing

Each power supply shall have a provision for implementing remote voltage sensing at the load. Input terminals for remote sensing cables should allow easy connection of individual shielded twisted cables (*e.g. Twinaxial Belden 9271; Trampeter TWC-124-LA; or equivalents.*) The expected input impedance between remote sensing terminals and common reference (e.g. chassis ground) should be high, in the range of 100K – 1Meg ohms. The differential input impedance must be no less than 100 ohms. Current-limiting resistors in the remote sending lines are included in the backplane of the crate, of value 1K ohms. ***Any variance must be approved by the Project Engineer.***

2.4.2 Remote Monitoring

Remote monitoring of voltages using computer readout is highly desirable.

2.4.2.1 If remote voltage monitoring is implemented, the communication interface must use a standard protocol. Acceptable protocols include: RS232, RS422, RS488, CANBus, or Ethernet. ***Any variance must be approved by the Project Engineer.***

2.4.2.2 If remote voltage monitoring is implemented, the digital interface must not create noise, either radiated or conducted, which can be picked up by the front end electronics.

2.4.2.3 If remote voltage monitoring is implemented, the ground and signal return of the data cable must be isolated from the local ground using techniques such as optical isolation, transformer coupling, or equivalent, to avoid creating ground loops that include the front end electronics.

2.4.2.4 If remote voltage monitoring is implemented, the operation of the power supply shall not be dependent on whether or not the readout is used. The power supply must be capable of functioning without it.

2.4.3 Remote Control

Control of power supply voltages using remote computer control is not required but is acceptable.

2.5 Load Protection, Fault Recovery, & Safety

2.5.1 Current Sensing

Current sensing for supply protection may be done using any technique that allows the supply to provide current limit protection in the case of a fault condition under full (nominal operating) load. See Section 3.

2.5.2 Current Limiting

2.5.2.1 The supplies shall have an adjustable current limit to protect against over-current conditions for the load. It must be possible to set the current limit to a level above the nominal operating load, but below the maximum rating of the supply. See Section 3.4.

2.5.2.2 Current limiting can include either constant current protect, or over-current protection, (OCP), where OCP represents catastrophic protection. If both are implemented, proper coordination between them is necessary, and it is assumed that the OCP limit is higher than the current limit. In this case, the power supply output voltage would be reduced if the current exceeds the current limit, and the power supply would shut down if the current exceeds the OCP limit.

2.5.3 Overload Protection and Recovery

The power supply units shall be capable of recovering from most overloads without physical attention. Specifically, it must recover from a momentary short circuit or a thermally induced shutdown when the conditions have been removed. Supplies that oscillate at high frequencies under overload conditions will not be acceptable.

2.5 Load Protection, Fault Recovery, & Safety (Cont.)

2.5.4 Over-Voltage Protection

The power supply shall limit the output voltage in the case of a component failure inside the supply or transients in the output circuit. Examples of component failures include a shorted pass transistor or a shorted rectifier.

2.5.4.1 For the +5V and -5V supplies, the maximum output voltage may not exceed 2 volts of the nominal voltage.

2.5.4.2 For the +12V and +3.3V supplies, the maximum output voltage may not exceed 1 volt of the nominal voltage.

2.5.4.3 For all other supplies, the maximum output voltage may not exceed 3 volts or 30% of the nominal voltage, whichever is greater.

2.5.5 Circuit Breakers and Switches on Input Power Lines

2.5.5.1 Each power supply set must have one line switch. It is ***not*** acceptable to have one line switch for each unit in a set.

2.5.5.2 It is ***desirable*** for the line switch to be a circuit breaker. If implemented, the circuit breaker shall not actuate for simple short circuits at the load, nor for thermal overloads. The function of the circuit breaker shall be reserved for protecting the mains and for safety

2.5.5.3 Fuses on the primary input lines are prohibited.

2.5.5 Internal Wiring

The wiring used inside the supply must be sized properly, according to accepted industry-standard safety specifications, based on the ampacity of the individual power supply units.

2.5.6 Output Fuses

The power supply ***may*** contain fuses for the DC outputs. If they are provided, they must be accessible without disassembling the power supply unit. Circuit breakers on the DC outputs are not allowed.

2.5 Load Protection, Fault Recovery, & Safety (Cont.)

2.5.7 Power Supply Rating vs. Wire Harness Gauge Size

The expected delivered current and rated current for each DC voltage are given in Section 3.2. The values for rated current represent a minimum requirement. We intend to design a wire harness between the power supply and the load that will safely accommodate the nominal load requirements. It is acceptable for the ampacity of the power supply units to exceed the listings for rated current shown in Table 1. Any safety requirements to safely protect the wire harness and the load from the maximum ampacity of the supply will be addressed outside the supply as needed, and will not be part of this specification. If fuses are provided on the DC outputs according to section 2.5.6, then we may elect to restrict current flow using this method. Otherwise, external fusing will be provided as part of the wire harness infrastructure.

2.6 Output Characteristics

2.6.1 Output Adjustment

Each output shall be settable to 10 mV over a +/- 250 mV range from the nominal value. It is preferred that this adjustment be internal to the supply, accessible only by removing a cover.

2.6.2 Output Isolation

The outputs of each unit shall be isolated from the chassis. Capacitance to the chassis shall be kept to the minimum practical value. Ground referencing shall be provided for and implemented at the load.

2.6.3 Multiple Outputs

Several of the voltages required in the system have high current loads. In these cases, the front end crate shall have two connections to the crate backplane for the current source, and two connections for the current return. The voltages that have lower current loads do not require the redundant outputs. The two types of outputs are shown in Figure 3. See Section 3 for the requirements for each voltage.

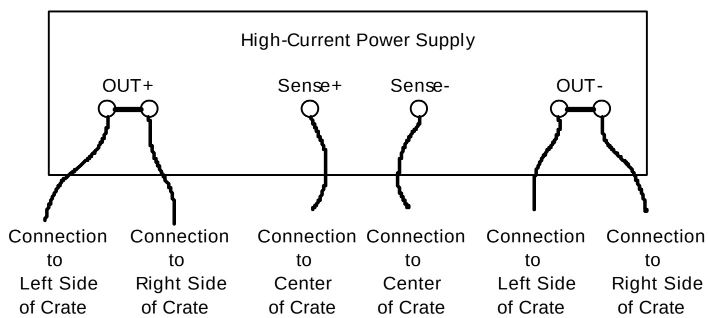

Figure 3A High-Current Output Connections

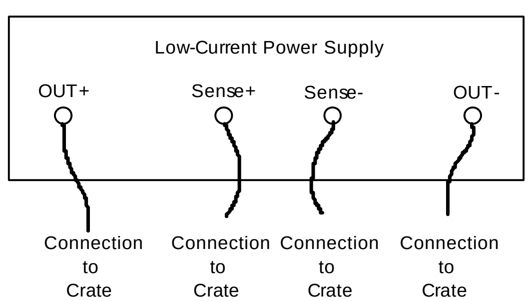

Figure 3B Low-Current Output Connections

2.7 Cooling

2.7.1 Description of Rack Cooling

2.7.1.1 The relay rack shall be equipped with water cooling and heat exchangers. The conceptual design is shown in Figure 4.

2.7.1.2 The relay rack shall have an air intake at the bottom of the relay rack. Air shall be exhausted at the top of the rack. The interior of the rack shall act as a chimney to funnel air from bottom to top.

2.7.1.3 The fan units that are part of the rack cooling system are rated at 970 cubic feet/min.

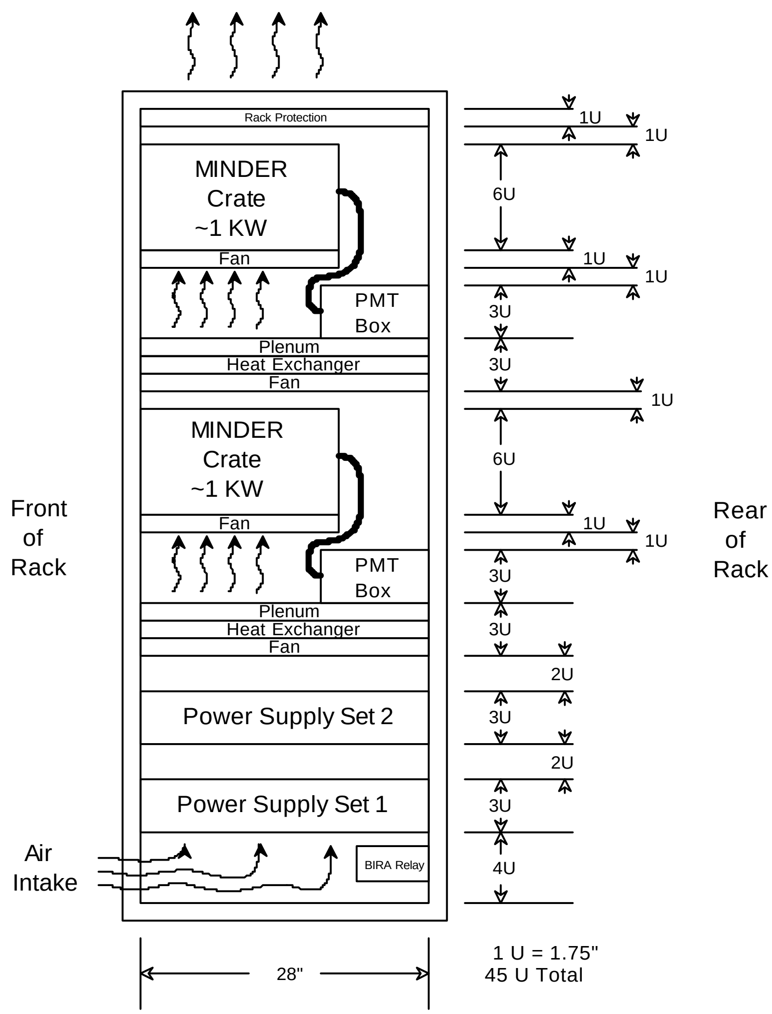

Figure 4. Conceptual Layout of Relay Rack

2.7 Cooling (Cont.)

2.7.2 Power Supply Cooling Requirements

2.7.2.1 The power supplies shall make use of the rack cooling system to remove heat from the rack. It is ***not*** acceptable for the heat from the power supplies to be shunted into the ambient air of the experimental hall.

2.7.2.2 The power supply case must be ventilated to allow air to flow in from the bottom, through the power supply, and be exhausted out the top.

2.7.2.3 The power supply sets must be capable of operation in the configuration shown in Fig. 3. If there are concerns about this configuration with respect to cooling, it is expected that these will be addressed with the Project Engineer.

2.7.2.4 The responsibility for providing the cooling capacity for the power supplies rests with the outfitting managers of the experiment.

2.7.2.5 It may be necessary or desirable to have fans inside the power supply to circulate air and prevent hot spots, if there are concerns about the cooling configuration described above. Space for additional fans must be accommodated in the space allocated for the power supply units, as described in Section 2.8.

2.8 Packaging

2.8.1 Available Space

The space available for the power supply sets for the rack is 8U high by 19" wide by 30" deep. This space must accommodate two power supply sets, as there are two front end crates in each relay rack. There must be room at the rear to accommodate the wire harness.

2.8.2 Packaging Guidelines and Constraints

2.8.2.1 Each power supply set ***shall*** be no larger than 3U in height, and be separate from the other set. No individual power supply may supply power to more than one crate.

2.8.2.2 Each power supply set ***must*** be readily accessible and removable from the front of the rack.

2.8.2.3 A power supply set ***must*** be capable of being removed independently from the other set.

2.8.2.4 Each set ***must*** have adequate cooling, as described in Section 2.7. In particular, one set may not block the ability to cool of the other set.

2.8.2.5 It is ***desirable*** but not required to have the individual units of a power supply set be capable of being swapped on an individual basis.

2.8.2.6 It is ***desirable*** to have the units of a power supply set be as lightweight as possible to aid in installation, servicing, and removal.

2.8.2. The connection of power cables to the supplies ***shall*** be made at the rear of the power supply set.

2.8.2.8 Power cables between the power supply sets and the crates are routed in the back of the rack. In the final configuration, access to the back of the supplies will be limited. It is ***desirable*** for the power supply sets to be configured using the concept of a mainframe, where the power supply units may be removed for servicing without removing the power connections.

2.8 Packaging (Cont.)

2.8.3 Packaging Examples

Several packaging possibilities are shown in Figure 5.

>> ***Open Design Issue*** <<

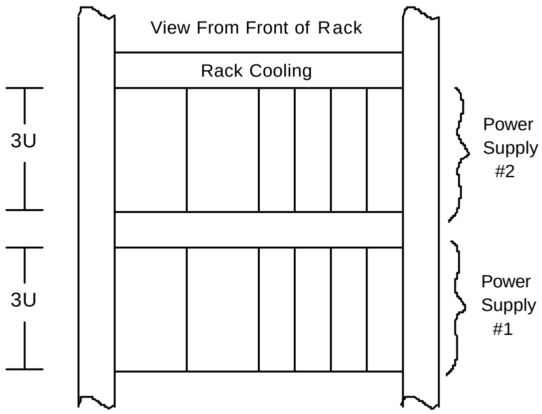

Figure 5A. Modular Package

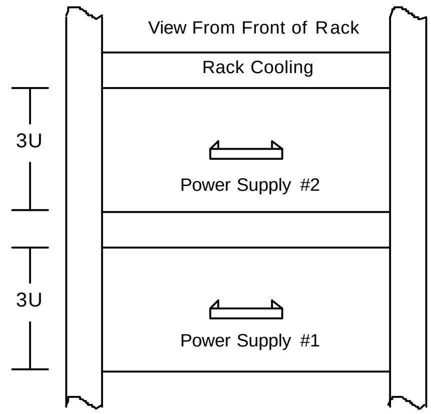

Figure 5B. Bulk Package

Discussion of packaging examples:

- Fig. 5A shows a short modular packaging scheme with two cooling units. Each set has identical cooling properties. The supplies may use the entire depth of the rack, providing that there is room for the wiring harness. The configuration may be housed in a crate, or the units may be separate. The scheme meets all of the criteria in Section 2.8.2.1 through 2.8.2.6, and is therefore a preferred solution.

- Fig. 5B shows a short bulk packaging scheme with two cooling units. The supplies are packaged in bulk, with all units integral to the set. Each set has identical cooling properties. As was the case above, the supplies may use the entire depth of the rack, providing that there is room for the wiring harness. The scheme meets all of the criteria in Section 2.8.2.1 through 2.8.2.4, but does not meet Section 2.8.2.5 (ability to swap individual units) nor Section 2.8.2.6 (lightweight). As the latter two criteria are only preferences, this configuration is acceptable but not preferred.

2.9 Input and Output Connectors

2.9.1 Line Cord

Each power supply unit shall have a 3-foot line cord. The plug shall have 4 prongs: one for each of the two line voltage phases; one for neutral; one for safety ground. (The plug is yet to be specified.)

2.9.2 Output Connectors

The output connector shall be such that current can be supplied to the load in a safe, reliable manner. The contact area must conform to safe wiring practices. (The exact type is yet to be specified.) It is desirable to use a modular connection system, so long as it meets the above criteria. Terminal lugs or screws are disfavored but acceptable.

>> ***Open Design Issue*** **<<**

2.9.3 Output Wiring Harness

The specification of the output wiring harness is not part of this project.

3. Specifications for Each Voltage

3.1 General Considerations

3.1.1 Delivered Current Defined

"Delivered Current" indicates the expected maximum current load from each voltage source for a fully populated crate.

3.1.2 Delivered Power Defined

"Delivered Power" indicates value of the maximum power delivered to the load for a fully populated crate. This value does not include power consumed by the supply. Cooling calculations shall use these values in conjunction with the values for power supply efficiency.

3.1.3 Rated Current Defined

"Rated Current" indicates the minimum value of the full output ampacity for each voltage. Generally, the power supplies will be operated at 65% of their Rated Current to enhance lifetime and mean-time-before-failure. The power supplies are ***not*** expected to operate at this level in the experiment. The power supplies shall be designed for the Rated Current values.

3.1.4 Rated Power Defined

"Rated Power" indicates the value of delivered power associated with the Rated Current. The power supplies are ***not*** expected to operate at this level in the experiment.

3.1.5 Current Limit Defined

"Current Limit" indicates the maximum value of the current that the power supply will be allowed to deliver to the load before limiting. The Current Limit is greater than the Delivered Current but less than the Rated Current. This represents the levels that we intend to operate at.

3.2 Ratings Defined

The voltages and current capabilities needed for each power supply set are shown in Table 1.

	VCC	VDIG	VANA1	VANA2	VANA3	VANA4
Voltage	+5 Volts	+3.3 Volts	-12 Volts	-5 Volts	+5 Volts	+12 Volts
Delivered Current	28 Amps	52 Amps	< 1 Amp	13 Amps	26 Amps	32 Amps
Delivered Power	140 Watts	170 Watts	<5 Watts	65 Watts	130 Watts	384 Watts
Rated Current	45 Amps	80 Amps	1 Amp	20 Amps	45 Amps	50 Amps
Rated Power	225 Watts	265 Watts	12 Watts	100 Watts	225 Watts	600 Watts

Table 1. Voltages and Currents for Each Power Supply Set

3.3 Output Types Defined

The type of output needed for each voltage is shown in Table 2. Refer to Section 2.6.3 for the output type configurations.

	VCC	VDIG	VANA1	VANA2	VANA3	VANA4
Voltage	+5 Volts	+3.3 Volts	-12 Volts	-5 Volts	+5 Volts	+12 Volts
Output Type	High Current Connection	High Current Connection	Low Current Connection	Low Current Connection	High Current Connection	High Current Connection

Table 2. Type of Output Needed for Each Voltage

3.4 Operational Current Limits Defined

The operational current limit for each voltage is shown in Table 3.

	VCC	VDIG	VANA1	VANA2	VANA3	VANA4
Voltage	+5 Volts	+3.3 Volts	-12 Volts	-5 Volts	+5 Volts	+12 Volts
Current Limit	35 Amps	60 Amps	1 Amp	15 Amps	35 Amps	40 Amps

Table 3. Operational Current Limits for Each Voltage

4. Expected Schedule and Milestones

Our tentative schedule is as follows:

Feb. 1, 2003 – Commit Order to Selected Vendor

Apr. 15, 2003 – Receive first Articles, 1-2 Units.

Jun. 1, 2003 – Receive 10 Units. ***(This is a firm requirement.)***

Nov. 1, 2003 – Order Complete

The delivery profile between the receipt of the first 10 units and the completion of the order is negotiable.

The total number of power supplies in the production order is 55.

We may initiate a separate order for prototype(s) to aid in evaluating proposals. This is negotiable,

5. Request for Proposals

We ask that prospective vendors evaluate the specifications in the preceding sections, and draft a conceptual design that meets as many of the specifications as possible. We ask that vendors produce documentation that describes the conceptual design, and includes the following:

5.1 An overall description of the power supply set, highlighting the prominent features.

5.2 A list of the performance specifications anticipated for the design.

5.3 A listing of the performance aspects that do not meet the specifications listed in the preceding sections.

5.4 A rough schedule for the development of the prototypes.

5.5 An estimated cost for the prototypes.

5.6 An estimated cost for the production units.

6. Technical Contacts

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